

LATEST RESULTS FROM PHOBOS AT RHIC

Gábor I. VERES^{4,*} for the PHOBOS Collaboration

B.B.Back¹, M.D.Baker², M.Ballintijn⁴, D.S.Barton², R.R.Betts⁶, A.A.Bickley⁷, R.Bindel⁷, W.Busza⁴, A.Carroll², Z.Chai², M.P.Decowski⁴, E.García⁶, T.Gburek³, N.George², K.Gulbrandsen⁴, C.Halliwell⁶, J.Hamblen⁸, M.Hauer², C.Henderson⁴, D.J.Hofman⁶, R.S.Hollis⁶, R.Holyński³, B.Holzman², A.Iordanova⁶, E.Johnson⁸, J.L.Kane⁴, N.Khan⁸, P.Kulinich⁴, C.M.Kuo⁵, W.T.Lin⁵, S.Manly⁸, A.C.Mignerey⁷, R.Nouicer^{2,6}, A.Olszewski³, R.Pak², C.Reed⁴, C.Roland⁴, G.Roland⁴, J.Sagerer⁶, H.Seals², I.Sedykh², C.E.Smith⁶, M.A.Stankiewicz², P.Steinberg², G.S.F.Stephans⁴, A.Sukhanov², M.B.Tonjes⁷, A.Trzupek³, C.Vale⁴, G.J.van Nieuwenhuizen⁴, S.S.Vaurynovich⁴, R.Verdier⁴, E.Wenger⁴, F.L.H.Wolfs⁸, B.Wosiek³, K.Woźniak³, B.Wysłouch⁴

¹ Argonne National Laboratory, Argonne, IL 60439-4843, USA

² Brookhaven National Laboratory, Upton, NY 11973-5000, USA

³ Institute of Nuclear Physics PAN, Kraków, Poland

⁴ Massachusetts Institute of Technology, Cambridge, MA 02139-4307, USA

⁵ National Central University, Chung-Li, Taiwan

⁶ University of Illinois at Chicago, Chicago, IL 60607-7059, USA

⁷ University of Maryland, College Park, MD 20742, USA

⁸ University of Rochester, Rochester, NY 14627, USA

**present address: Department of Atomic Physics, Eötvös Loránd University
Pázmány Péter sétány 1/A, Budapest H-1117, Hungary*



A study of charged hadron production in d+Au and Au+Au collisions is presented at various collision energies ($\sqrt{s_{NN}}$ =19.6 to 200 GeV). Scaling and factorization features of p_T and η distributions and v_2 are discussed as a function of $\sqrt{s_{NN}}$ and collision centrality.

1 Introduction

The study of heavy ion collisions constitutes an important part of the recent experimental and theoretical effort to understand the strong interaction which binds quarks and gluons into hadrons. Predictions based on QCD indicate the existence of a new state of matter dominated by the strong interaction, where bound hadrons no longer exist, provided the energy density

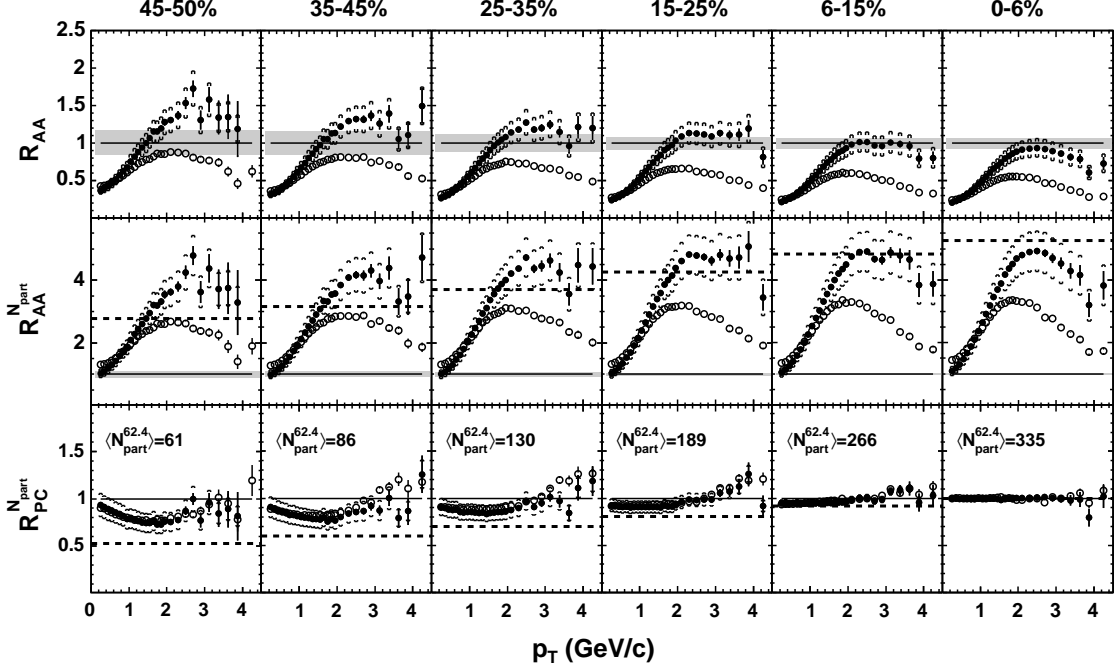


Figure 1: Ratio of p_T distributions from Au+Au collisions to various reference distributions at $\sqrt{s_{NN}}=62.4$ GeV (filled symbols) and 200 GeV (open symbols), in six centrality bins. The R_{AA} , $R_{AA}^{N_{part}}$, $R_{PC}^{N_{part}}$ quantities are discussed in the text. The dashed line is the N_{coll} scaling expectation; the gray band is the uncertainty of N_{coll} .

is sufficiently high (greater than a GeV/fm^3). Heavy ion collisions are the only method to create such a high energy density in the laboratory. The current understanding of the phase structure of strongly interacting matter, the properties of the matter in the various phases and the nature of the transition between them is, to a large extent, driven by experiment. One of the important discoveries at the Relativistic Heavy Ion Collider (RHIC) is that an extremely high energy density system is created, where hadronic degrees of freedom cannot be relevant any more. There is evidence for a very significant level of interaction between the constituents of this system, as opposed to earlier expectations.

In this experimental talk we will emphasize a few basic scaling and factorization features of the data collected by the PHOBOS experiment at RHIC, in comparison with earlier measurements. These simple rules highlight common features of collisions of heavy ions (Au+Au) and simpler systems (d+Au, p+p) in a broad range of collision energies ($\sqrt{s_{NN}}=6.7$ to 200 GeV). Details of these findings can be found in a volume summarizing the results of the four experiments from the first three years of RHIC, in which our contribution¹ is titled ‘The PHOBOS Perspective on Discoveries at RHIC’. To collect the data presented here, we used the magnetic spectrometer and the multiplicity arrays (covering the $|\eta| < 5.4$ pseudo-rapidity region) of the PHOBOS experiment (described in detail elsewhere²).

2 Scaling features in heavy ion data

We concentrate on three topics: transverse momentum (p_T) and pseudo-rapidity (η) distributions of charged hadrons, and the azimuthal asymmetry of their production which is called elliptic flow. The consensus in the heavy ion community is that in the early stage of high energy heavy ion collisions a new state of strongly interacting matter has been created. The above observables are related to relevant physical characteristics of this newly created matter, such as the suppression of high- p_T particles (jet quenching); the initial energy density and entropy after the collision and the boost-invariance of particle production along the colliding beam direction;

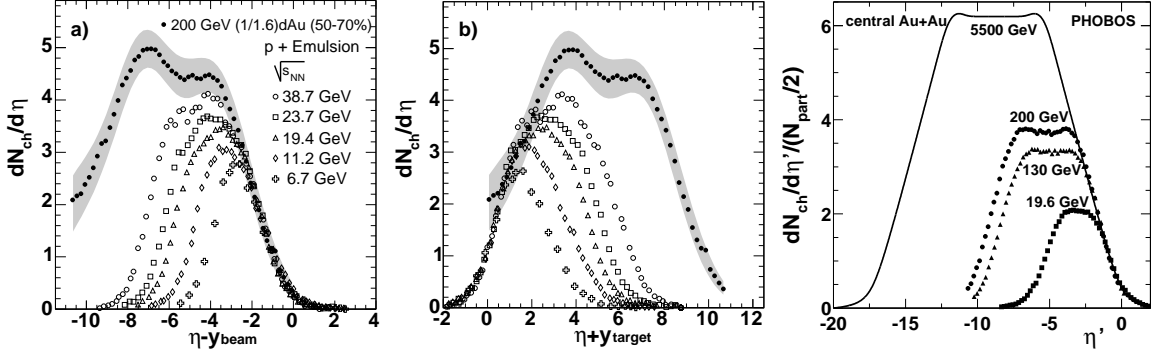


Figure 2: Pseudo-rapidity density distributions of charged particles measured in p+Emulsion and d+Au collisions at various energies, approximately shifted to the rest frame of the lighter (a) and heavier (b) species. On the rightmost panel, scaling features of Au+Au data are used to predict the η' distribution at the LHC (Pb+Pb).

and the collective motion of particles resulting from secondary interactions and the properties of the equation of state.

Determining the **centrality** of a heavy ion collision is essential to provide the basis of comparison with more elementary (p+p, p+ \bar{p}) processes. Instead of the impact parameter, two different quantities are used to quantify the centrality: the number of participant nucleon pairs ($N_{part}/2$) and the number of binary nucleon-nucleon collisions (N_{coll}). Since the nucleon-nucleon cross section increases with collision energy, so does the N_{coll}/N_{part} ratio, which also grows with decreasing impact parameter for simple geometrical reasons. These two quantities are calculated by measuring the charged hadron multiplicity in various regions of η , combined with a comprehensive Monte-Carlo simulation including the Glauber model.³

If one normalizes the **transverse momentum distribution** of charged hadrons measured in different centrality bins to the p_T distribution measured in p+p(\bar{p}) collisions and also divides by N_{coll} , one observes a gradual decrease of this quantity (R_{AA}) with decreasing impact parameter (Fig. 1). Note that the expectation for ‘hard’ collisions with large momentum transfer and no re-interaction with the created medium would be a constant R_{AA} equal to unity. However, the $R_{AA}^{N_{part}}$ quantity (where we replaced N_{coll} by N_{part} in the denominator) scales with centrality much more precisely in Au+Au collisions at $\sqrt{s_{NN}}=62.4$ and 200 GeV,⁵ pointing to new physical interpretations.⁴ More strikingly, the p_T spectra normalized to the most central bin at each energy, and also normalized by N_{part} , as illustrated in the bottom row of Fig. 1, are identical within errors in each of our centrality bins. This is a clear factorization of collision energy and centrality. It will be interesting to compare these conclusions to the data from half a billion Cu+Cu events taken in the present RHIC run, since, for the same number of participants, the collision zone will have a very different geometry in the Cu+Cu and the Au+Au events.

Another simple feature of the data is the **extended longitudinal scaling of pseudo-rapidity (η) density** distributions of charged particles, in p+Emulsion and d+Au,¹ as shown in Fig. 2. By plotting these distributions as a function of $\eta' = \eta \pm y_{target}$, thus effectively looking at them from the rest frame of one of the colliding beams, we observe that the data at various energies fall on a common limiting curve, in both reference frames. The longitudinal scaling extends over more than an order of magnitude in beam energy.

A similar scaling was observed earlier in heavy ion (Au+Au) collisions by PHOBOS, illustrated on the right panel of Fig. 2 for the 6% most central data. In addition, applying the fact that $dN/d\eta$ at $\eta \approx 0$ in central collisions scales logarithmically with $\sqrt{s_{NN}}$, we can extrapolate the $dN/d\eta$ distribution to LHC energies and give a simple experiment-based prediction at $\sqrt{s_{NN}}=5500$ GeV. The prediction gives $dN/d\eta|_{\eta=0} \approx 1100$ and 14000 charged particles in total.⁶

Longitudinal scaling has also been recently observed in the **elliptic flow** of particles pro-

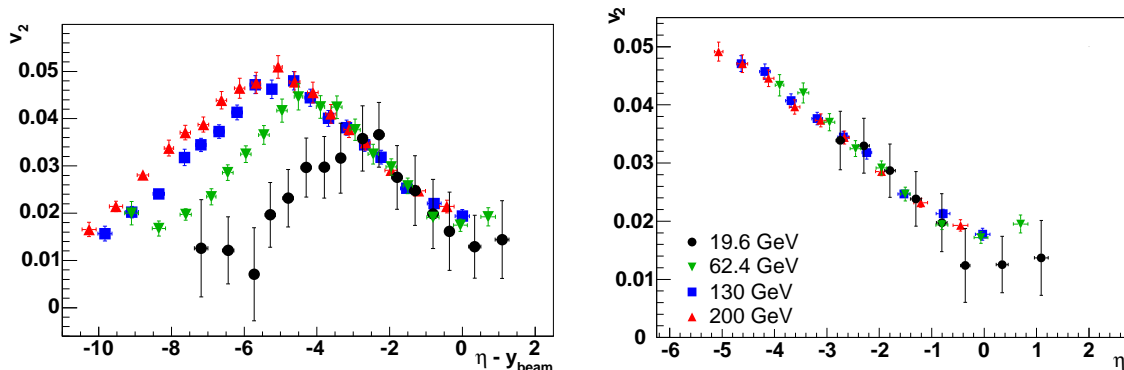


Figure 3: The elliptic flow parameter v_2 , averaged over centrality (0-40%), as a function of $\eta' = \eta - y_{beam}$ (left) and $|\eta| - y_{beam}$ (right) for various collision energies (Au+Au). Only statistical error bars are shown.

duced in heavy ion collisions.⁷ The elliptic flow parameter (v_2) is a sensitive probe of the properties of the newly created, very dense and hot matter in the early stage of the collision. In Fig. 3, the pseudo-rapidity dependence of this v_2 parameter is plotted for semi-central Au+Au events and for various energies, where we use the $\eta' = \eta - y_{beam}$ parameter again. There seems to be a universal curve governing v_2 over a broad range of η' . This is shown more precisely on the right panel of Fig. 3, where we used the symmetry and plotted v_2 as a function of $|\eta| - y_{beam}$.

3 Conclusions

We reported a few simple scaling and factorization properties of charged hadron production in heavy ion collisions at RHIC energies. We observed that the transverse momentum spectra approximately scale with the number of participant nucleons, and the energy and centrality dependence of these spectra precisely factorize in the range of centrality and p_T we studied. Longitudinal scaling was seen in an extended pseudo-rapidity region in Au+Au (and d(p)+A) collisions, both in case of the $dN/d\eta$ pseudo-rapidity density and in case of the v_2 elliptic flow parameter. These simple features of the data impose constraints on models attempting to describe and understand the basic particle production mechanism in heavy ion collisions.

Acknowledgments

This work was partially supported by U.S. DOE grants DE-AC02-98CH10886, DE-FG02-93ER40802, DE-FC02-94ER40818, DE-FG02-94ER40865, DE-FG02-99ER41099, and W-31-109-ENG-38, by U.S. NSF grants 9603486, 0072204, and 0245011, by Polish KBN grant 1-P03B-062-27(2004-2007), by NSC of Taiwan Contract NSC 89-2112-M-008-024, and by the Hungarian Scientific Research Fund (OTKA F049823) and the János Bolyai Research Grant.

References

1. B. B. Back *et al*, *Nucl. Phys. A* **757**, 28 (2005) and references therein.
2. B. B. Back *et al*, *Nucl. Instrum. Methods A* **499**, 603 (2003)
3. R.S. Hollis *et al*, *J.Phys.Conf.Ser.* **5**, 46 (2005).
4. B. Müller, *Phys. Rev. C* **67**, 061901 (2003).
5. B. B. Back *et al*, *Phys. Rev. Lett.* **94**, 082304 (2005).
6. W. Busza *Acta Phys. Polon.* **B35**, 2873 (2004).
7. B. B. Back *et al*, *Phys. Rev. Lett.* **94**, 122303 (2005).